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## The role of contagious disease in udder health

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### Abstract

Contagious diseases are a threat to animal health and productivity, both nationally and at the farm level. This makes implementation of biosecurity measures to prevent their introduction and spread within countries and farms a necessity. Mastitis is the most common and costly contagious disease affecting dairy farms in the western world. The major mastitis pathogens are endemic in most countries, and biosecurity measures to prevent introduction and transmission must therefore be implemented at farm level. The 40-yr-old mastitis control plan remains a solid foundation to prevent the spread of contagious intramammary infections. Contagious diseases that do not affect the mammary gland directly may have an indirect effect on mastitis. This is true for list A diseases such as foot and mouth disease, for which biosecurity measures may need to be taken at national level, and for other infections with nonmastitis pathogens such as bovine viral diarrhoea virus and *Mycobacterium avium* ssp. *paratuberculosis*. Maintaining a closed herd decreases the risk of introduction of pathogens that affect udder health directly or indirectly. If animals are purchased, their udder health history should be evaluated and they should be examined and tested for contagious diseases. Transmission of infections by and to humans and nonbovine animals may occur. Contact with visitors and nonbovine animals should therefore be minimized. Because of globalization and heightened consumer awareness, the importance of biosecurity now supersedes individual farms, and increased pressure to control transmission of contagious diseases can be expected at industry or government levels in western countries and elsewhere.

### Keywords

mastitis; biosecurity; infection; contagious transmission

## INTRODUCTION

With the proliferation of international trade, globalization, and global warming, the importance of the control of contagious and infectious diseases has increased dramatically. Pathogens are emerging in areas where they were not endemic before, such as Bluetongue virus in Northern Europe and West Nile Virus in the United States. Rinderpest is the only

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infectious disease of cattle that may have been eradicated worldwide (FAO, 2009). For countries that depend heavily on the export of animal products, freedom from diseases listed by the World Organization for Animal Health (**OIE**), such as foot and mouth disease (**FMD**), is particularly important. Being free of a disease, however, automatically implies that reintroduction is a threat. At a national level, minimizing the probability of introduction of eradicated diseases and maintaining contingency plans for when such diseases are inadvertently or intentionally introduced are essential policies. At the individual farm level, infectious diseases are a threat to animal health and welfare, production efficiency, and product quality, and biosecurity measures to prevent their introduction and spread within the herd are a necessity.

The threat from pathogens that are specifically deleterious to mammary health is illustrated by examples of the introduction of *Mycoplasma* spp. in some larger farms in the United States (González and Wilson, 2003). Introduction of pathogens that do not directly cause mastitis but that can have implications for udder health, such as bovine viral diarrhea virus (**BVDV**), also needs consideration in terms of maintaining mammary health through biosecurity.

In this article, we first review the effect of introduction of contagious infectious diseases, epidemic and endemic, on the incidence and prevalence of mastitis on dairy farms. Second, we will evaluate the role that biosecurity can play on individual dairy farms to prevent introduction and on-farm transmission of infections with pathogens that affect udder health directly or indirectly.

## CONTAGIOUS MASTITIS PATHOGENS AND UDDER HEALTH

Several contagious mastitis pathogens are endemic in most countries with a dairy industry, but not necessarily within every farm. The most notable ones are *Streptococcus agalactiae* and *Mycoplasma* spp. Introduction of such pathogens into herds should be avoided through biosecurity measures. Even if a herd is already infected with a certain bacterial species; for example, *Staphylococcus aureus*, care is still required to prevent the introduction of animals infected with that species because purchased animals may introduce a new strain of the pathogen (Middleton et al., 2002). Newly emerged strains of mastitis pathogens may cause outbreaks of mastitis, even when transmission of other strains of the same bacterial species is adequately controlled by existing management measures (Smith et al., 1998; Zadoks et al., 2003).

### **Streptococcus agalactiae**

In many countries, IMI with *Strep. agalactiae* is still common (Zadoks and Fitzpatrick, 2009). However, in several countries with a developed dairy industry the majority of dairy farms have become free of *Strep. agalactiae* (e.g., Andersen et al., 2003; Olde Riekerink et al., 2006; Piepers et al., 2007; Sampimon et al., 2009). In some countries and regions, mandatory eradication of this pathogen from the small number of herds that are positive has been considered (Andersen et al., 2003; Hillerton et al., 2004). Eradication is straightforward if farmers comply with recommended control strategies (Neave et al., 1969; Loeffler et al., 1995), although anecdotal reports suggest re-emergence of *Strep. agalactiae* in some European countries (e.g., Finland, S. Pyörälä, University of Helsinki, Department of Production Animal Medicine, Saarentaus, Finland; personal communication, 2009; Denmark, J. Katholm, Royal Veterinary and Agricultural University, Department of Clinical Studies, Frederiksberg, Denmark; personal communication, 2009). Farmers who do not or cannot implement this program (e.g., organic dairy farms with restrictions on use of antimicrobials for treatment of IMI; farms that do not have routine access to diagnostic facilities or treatment products) are at greatest risk of a major outbreak of infection with

*Strep. agalactiae*. If a cow with a *Strep. agalactiae* IMI is purchased and introduced into a herd that complies with the contagious mastitis control program, the likelihood that the infection will spread to a major proportion of the herd is relatively low. On rare occasions, an animal or bulk tank sample may test positive for *Strep. agalactiae* because of the presence of a human strain of the organism (Zadoks and Schukken, 2006).

## Mycoplasma

Prevalence of *Mycoplasma* mastitis has increased in several countries (Fox et al., 2005). *Mycoplasma* has been a major cause of clinical mastitis in large and expanding dairy farms in the southern United States (González and Wilson, 2003; Fox et al., 2005). The infection is often introduced by a purchased heifer. Contagious mastitis control procedures contribute to control of outbreaks of *Mycoplasma* mastitis. *Mycoplasma* control, however, relies heavily on test-and-cull, which is different from the treatment-based approach used in control of *Strep. agalactiae*. Additionally, diagnosis of *Mycoplasma* infections is more challenging because of variable shedding of the organism in milk. Current data suggest that a significant number of new outbreaks may occur via internal or animal-to-animal transmission of *Mycoplasma* by asymptomatic carriers within the herd (Fox et al., 2005). On-farm transmission may furthermore be maintained through aerosols from animals with respiratory *Mycoplasma* infection. Some states in the United States, such as Louisiana, have introduced a statewide control program for *Mycoplasma* mastitis in dairy herds (Owens and Nipper, 2008). After the first case was identified in Louisiana in September 2002, a monitoring program was started. Bulk milk of all farms was cultured monthly to detect *Mycoplasma*-positive herds. In positive herds, composite samples of all lactating cows were cultured and movement of cows from such herds was restricted. The prevalence of *Mycoplasma* in bulk milk in Louisiana has substantially decreased since the first case was recognized, and the frequency of bulk tank culture has been reduced to quarterly monitoring (Owens and Nipper, 2008).

## Staphylococcus aureus

*Staphylococcus aureus* is a common cause of mastitis on dairy farms (e.g., Olde Riekerink et al., 2008) and the most frequently isolated major pathogen in heifer mastitis (Borm et al., 2006). Although control of *Staph. aureus* mastitis is often deemed to be difficult, many herds have successfully achieved this through implementation of the standard mastitis prevention program (e.g., Hillerton et al., 1995; Zadoks et al., 2002; Barkema et al., 2006). As a result, the prevalence of *Staph. aureus* IMI has decreased in several European countries (e.g., Pitkälä et al., 2004; Bradley et al., 2007).

Recently, methicillin-resistant *Staph. aureus* (MRSA) of animal origin has become an important public health concern. Pig farming in particular is associated with a high prevalence of MRSA, but MRSA has also been identified as a cause of mastitis in dairy cattle (Juhász-Kaszanyitzky et al., 2007; Moon et al., 2007; Wulf and Voss, 2008). Strain typing of MRSA isolates from cattle and humans suggests the possibility of zoonotic transmission, although it is not always clear whether infections are transmitted from humans to animals or from animals to humans (Devriese and Hommez, 1975; Lee, 2003; Juhász-Kaszanyitzky et al., 2007). In the Netherlands, veal and pig farmers were at greater risk of harboring MRSA than the general population (Vandenbroucke-Grauls and Beaujean, 2006; Van Reijen et al., 2008). Antibacterial susceptibility testing of *Staph. aureus* isolates from bovine mastitis cases (clinical and subclinical) submitted to the Animal Health Diagnostic Laboratory of Michigan, from 1994 to 2000, showed that 99.4% of 846 isolates were susceptible to cloxacillin (Erskine et al., 2002). Of 2,132 *Staph. aureus* isolates obtained from milk samples submitted to the Wisconsin Veterinary Diagnostic Laboratory from 1994 to 2001, 1.8% were resistant to cloxacillin (Makovec and Ruegg, 2003). Because of the

significance of MRSA infection in humans, and the common use of cloxacillin, an antimicrobial similar to methicillin/oxacillin, for mastitis treatment or prevention, pressure on the dairy industry to monitor MRSA infections is increasing. Even though the effect of MRSA on udder health is not known to be different from the effect of other *Staph. aureus* on bovine udder health, the potential impact on human health may result in the need for stricter control measures.

### Other Mastitis Pathogens

Several other mastitis pathogens are thought to have the potential to spread in a contagious manner. This is particularly true for *Strep. dysgalactiae* (Neave et al., 1969; Fox and Gay, 1993) and to a lesser extent for *Strep. canis* (Hassan et al., 2005; Tikofsky and Zadoks, 2005) and *Strep. uberis* (Neave et al., 1969; Zadoks, 2007). For *Escherichia coli*, adaptation to the bovine host has been described (Bradley and Green, 2001). As of yet, there are no reports of contagious transmission but biosecurity measures to prevent transmission of such mammary-adapted strains may become necessary. For *Klebsiella pneumoniae*, another important cause of coli-form mastitis, transmission via the milking machine or through contamination of bedding material by infected cows has been suggested (Muñoz et al., 2007). Based on strain-typing studies of *Staphylococcus chromogenes*, *Staphylococcus hyicus*, and *Staphylococcus epidermidis*, contagious transmission of coagulase-negative staphylococci appears to be relatively rare (Gillespie et al., 2009; Sawant et al., 2009). Segregation of animals with clinical or subclinical mastitis could prevent transmission of mammary pathogens via fomites or the environment, regardless of whether the pathogens are considered to be contagious or opportunistic infectious agents.

## NONMASTITIS PATHOGENS AND UDDER HEALTH

### List A Diseases

In the last 2 decades, several outbreaks of OIE list A diseases (OIE, 2006) have occurred in areas where these diseases are not endemic. Examples are the Bluetongue outbreak in northern Europe that started in the fall of 2006, the 2000-2001 FMD outbreaks in the United Kingdom and the Netherlands, and the occurrence of bovine spongiform encephalopathy (BSE) in North America in 1993. In North America, the incidence of BSE is very low, but the disease has had a major effect on the cattle industry, particularly in Canada (Tyshenko, 2007). Such outbreaks affect the farms that experience the disease, neighboring farms, the whole farming sector and its supply chain, and more distantly related industries such as tourism (Thompson et al., 2002). Of specific interest for the current review is the effect of outbreaks of OIE list A diseases on mastitis. As an example, we will describe the 2001 FMD outbreak in the Netherlands.

In March 2001, an outbreak of FMD occurred in the Netherlands (Bouma et al., 2003). The first infected farm was not a dairy farm, but comprised goats and veal calves. The infection was probably introduced by Irish veal calves transported through the UK and France where they were infected via contact with animals originating from the UK. The infection was subsequently transferred to dairy farms by various routes of transmission (Bouma et al., 2003). Ultimately, 26 farms became infected and a region in the center of the Netherlands was depopulated of susceptible species. Indirect sequelae of the outbreak included a general movement ban for transport of livestock in the whole country and discontinuation of DHI testing. Although it was clear that bulk milk SCC (BMSCC) was increasing on many farms during the FMD outbreak, farmers did not know which animals were responsible for the increase, because individual cow SCC could not be determined. Additionally, cows with mastitis or high SCC could not be culled for 2 mo because of the transport ban. The overall result was an increase in the national BMSCC (Figure 1). On nearly 2,000 farms,

approximately 260,000 animals, including more than 71,000 cattle, were culled under the depopulation scheme (Bouma et al., 2003). Some farmers chose not to have their farms restocked, but most repopulated their farms with animals from multiple origins. The risk of introduction of pathogens when restocking farms is high. For example, restocking of cattle from farms with a perceived high risk of bovine tuberculosis after the 2001 FMD epidemic in the UK increased the risk of introduction of bovine tuberculosis (Carrique-Mas et al., 2008). Introduction of pathogens, combined with the lack of opportunity for selection due to shortage of replacement animals, may partly explain why BMSCC in the Netherlands continued to be high after the FMD outbreak had ended (Figure 1). By contrast, evaluation of data from the first year of the Bluetongue outbreak in the Netherlands showed a negative effect on milk yield but not on SCC (Van Schaik et al., 2008).

### Other Diseases

Several infections with nonmastitis pathogens appear to be associated with udder health in a dairy herd. Probably the best documented is infection with BVDV, although the mechanism has not been unraveled and it is uncertain to which extent association is causal. In Norwegian herds that had a marked increase in BVDV antibodies in the bulk milk, the incidence rate of clinical mastitis was 7% higher than in herds that did not (Waage, 2000). In a large Dutch observational study, the incidence of new high SCC cases was lower in herds that became BVDV-free than in herds that did not (Berends et al., 2008). In the Norwegian and Dutch studies, BMSCC was not affected. In a French study, BMSCC was higher in BVDV-positive herds than in BVDV-negative herds (Beaudeau et al., 2005). Like BVDV, bovine herpesvirus 1 (**BHV-1**), bovine immunodeficiency virus, and bovine leukemia virus infections may play an indirect role in bovine mastitis, probably because of their immunosuppressive properties (Wellenberg et al., 2002). Other viruses that can affect udder health include bovine herpesvirus 2, vaccinia, cowpox, pseudocowpox, vesicular stomatitis, foot-and-mouth disease viruses, and bovine papillomaviruses. These viruses induce teat lesions, which may predispose the animal to bacterial udder infections (Wellenberg et al., 2002). A specific role for bovine herpes virus 4 (**BHV-4**) in mastitis has been suggested (Wellenberg et al., 2002). Other authors state that BHV-4 does not play a role in causation of mastitis, but that reactivation of the virus by mastitis may contribute to more severe or prolonged mastitis episodes (Kálmán et al., 2004).

Any disease or condition (e.g., lameness or poor fertility) that significantly affects culling rates may affect BMSCC because it reduces opportunities for selection and culling based on SCC and thus increases the risk of within-herd transmission of contagious mastitis. Changes in farm business strategy, such as herd expansion, are another reason to limit culling of cows affected by mastitis (Faust et al., 2001; Hadley et al., 2006; Villarroel et al., 2007). Implications of herd expansion for mammary gland health and milk quality should be carefully considered and need to include aspects of animal and personnel availability and management. Another factor often overlooked is the potential influence of milk quality payment thresholds; such bonus/penalty thresholds are often implemented in more “developed” markets. Data from a US dairy cooperative showed that the probability of producing milk with BMSCC <100,000 cells/mL could double during high premium periods, and an associated 10% increase in the probability of producing milk with BTSCC <200,000 cells/mL was observed (Nightingale et al., 2008). Conversely, an increase in BMSCC payment/bonus threshold will encourage farmers to retain cows with high SCC because their retention in the herd will increase output and can be tolerated without directly affecting milk price. The implication of such a practice is an increase in infectious pressure within the herd.



A disease that significantly increases culling risk is Johne's disease (McKenna et al., 2006b), caused by infection with *Mycobacterium avium* ssp. *paratuberculosis* (**MAP**). The herd-level prevalence of MAP infection is high in nearly all countries with a significant dairy industry (McKenna et al., 2004; USDA-APHIS-VS, 2007; Nielsen and Toft, 2009). Results from a study of dairy cattle in Maritime Canada indicated that, after controlling for parity, 305-d milk production, and SCC, the odds of being culled was 1.4 times greater in MAP ELISA-positive cows than in ELISA-negative cows (Tiwari et al., 2005). At the farm level, high prevalence of MAP antibody-positive cows has been associated with high levels of BMSCC and clinical mastitis (Diéguez et al., 2008). As for BVDV, the mechanism and causality of this association are unknown, but reduced opportunity for selection could be part of the explanation.

Most foodborne pathogens; for example, *Salmonella*, *Listeria monocytogenes*, *Campylobacter*, and *E. coli* O157:H7, either do not cause or contribute to the risk of mastitis or do so only sporadically. Several of these pathogens are commonly present on dairy farms (Murinda et al., 2004), and it is nearly impossible to take biosecurity measures to prevent their introduction. To reduce the prevalence of *L. monocytogenes*, silage quality is more important than biosecurity (Nightingale et al., 2005). For control of *Salmonella* infections in dairy herds, both internal and external biosecurity measures are important (Nielsen et al., 2007). The presence of foodborne pathogens in milk has been associated with outbreaks of disease in humans (Leedom, 2006). Thus, the importance of these pathogens arises from their potential effect on milk quality rather than as a cause of mastitis.

## PREVENTION OF INTRODUCTION

### Mastitis Pathogens

Cows purchased into the dairy herd may be infected with mastitis pathogens and are a possible risk to other cows in the herd. Although this risk can never be totally avoided, it can at least be minimized by taking appropriate biosecurity measures. A farm should have a written policy (standard operating procedure or protocol) for biosecurity, developed in consultation with its veterinarian (Dinsmore, 2002; Cannas da Silva et al., 2006). Although this is also important on small farms, it is essential on large farms that employ multiple people, especially in the case of personnel with different levels of education and knowledge of the dairy industry or speaking different languages (e.g., Stup et al., 2006). As dairy farms around the world increase in size, purchase of animals is often necessary. Herd expansion through acquisition rather than internal herd growth implies the risk of introduction of infections. However, larger herds may also have increasingly highly qualified personnel, more opportunities to separate groups, a greater ability to invest in laboratory testing, and more development of on-farm biosecurity programs, all of which may mitigate problems associated with herd expansion.

To prevent the introduction of mastitis pathogens when purchasing cows, a balance has to be struck between minimizing the probability of purchasing an infected cow and maintaining sufficient choice in the population from which to select replacements. This balance is influenced by the farm attitude to risk, the degree of risk acceptable for purchasing an infected cow, and the likely consequences for the herd of introducing a new pathogen (Gunn et al., 2008). In general, it is pragmatic to implement strategies that increase the sensitivity of diagnostic methods at the expense of specificity (i.e., it is better to detect as many infected cows as possible even if some uninfected cows are rejected). The strategies described below may be too onerous for some farms to adopt, but the measures were successfully included in a holistic mastitis control plan in the UK that was demonstrated to improve mastitis in a randomized clinical trial (Green et al., 2007b).

To minimize the risk of buying infected cattle, it is sensible to set some standards that apply to the herd of origin. For example, 1) the herd should have had a rolling geometric mean herd SCC <200,000 cells/mL for at least 1 yr (or lower in countries with a low BMSCC such as in some Scandinavian countries); 2) the herd should have individual cow SCC recorded, preferably monthly but at least every 2 mo, for the previous 6 mo; 3) the herd must not have had *Strep. agalactiae* infections in the last 2 yr; 4) the herd should be BVDV-free or vaccinated; 5) the herd must not have cows with severe teat lesions; and 6) the herd-owner should provide truthful information on pathogens present on farm. However, knowledge of pathogen presence and attitudes toward disclosure are vastly different between countries. Additionally, in countries with a high awareness of the importance of biosecurity, herds that cease farming activities are not necessarily the herds with the best information on pathogen presence. Some of this information is publicly available in some countries (e.g., *Salmonella* status in Denmark; Nielsen and Ersbøll, 2005), whereas in other countries no information would be available.

Although heifers can become infected with mastitis bacteria before they calve for the first time (Fox, 2009), they may (depending on source) be at less risk than older cows. Therefore, purchase of pregnant nonlactating heifers from an established, well-managed source is often preferable over purchase of older animals. In regions with a high prevalence of *Staph. aureus* or *Mycoplasma* IMI in young stock, this may not apply (González and Wilson, 2003; Nickerson, 2009). If older cows are purchased, they should preferably only be purchased with whole lactation SCC records (see below), and if possible after quarter milk is cultured and found to be negative for contagious pathogens (Dinsmore, 2002). Because of variable shedding, a single culture may fail to reveal presence of IMI caused by *Staph. aureus* or *Mycoplasma* (Biddle et al., 2003; Sears and McCarthy, 2003) and it should be acknowledged that bacteriological culture is not a foolproof method for identification of IMI.

In the absence of or in combination with culture results, SCC records provide a useful basis for decisions on the probability of major pathogen infections. Somatic cell concentrations in milk are used as indicators of mammary health on the basis that they reflect an immune response and therefore the presence of infection. An SCC <100,000 cells/mL is often considered to be “normal” in a healthy mammary gland (quarter) (Sordillo et al., 1997; Schukken et al., 2003), whereas an SCC >200,000 cells/mL is suggestive of bacterial infection (Brolund, 1985; Schepers et al., 1997; Schukken et al., 2003). However, there is not a discrete threshold cow SCC value that can be used to identify all infected and uninfected cows (Dohoo and Meek 1982; Bradley and Green, 2005). The commonly used cut-off of 200,000 cells/mL has a sensitivity and specificity of approximately 70 to 80% (Dohoo and Meek, 1982). As the chosen SCC threshold is decreased, the sensitivity of IMI detection increases and the specificity decreases. In the UK the following recommendations were made regarding SCC of purchased cows when implementing a national mastitis control intervention study (Green et al., 2007b): 1) the cow should, in the last lactation, not have had a test-day SCC in excess of 200,000 cells/mL, and 2) the cow should have at least the 3 most recent SCC in current lactation <100,000 cells/mL. It may be reasonable in some countries (e.g., Norway or Sweden) to require the 3 most recent SCC readings to be <50,000 cells/mL and thus increase the sensitivity of identification of IMI further. When considering SCC data it is important to note that such information will not be available in herds that do not participate in a milk recording program. Purchase of a cow from a nonrecorded herd should therefore be considered high risk. Attention should be also paid to the possibility of cows not being present at a test day (missing SCC records). Because this could be as a result of clinical mastitis, such cows should also be considered high risk.



Before addition of newly purchased animals to the herd, it is also pragmatic to consider the following as good clinical practice: 1) udder, teats, and milk being examined for signs of abnormalities on arrival; 2) the cow being milked last until all cow-side SCC tests show low SCC for 3 consecutive days; and 3) it being possible to send cows back to the vendor if any mammary gland abnormalities are found within 2 wk of purchase. If the vendor chooses not have the animal returned to the farm of origin, an agreement could be made that this animal would go for slaughter.

Preferably, a dairy herd should be closed (i.e., no purchase of animals), with barriers to outside animals and people. People can harbor mastitis bacteria and there may be transmission between humans and cows (Roberson et al., 1994; Juhász-Kaszanyitzky et al., 2007). Therefore, the number of relief milkers should be minimized and external personnel should not be allowed to handle cows in the parlor. On dairies with hired labor, education of personnel on personal hygiene, biosecurity measures, and mastitis prevention is important, together with provision of adequate sanitary and hand-washing facilities and training in their use (Villarroel et al., 2007). Dogs and cats may carry pathogens, specifically *Strep. canis*, which can cause mastitis outbreaks (Tikofsky and Zadoks, 2005). Dogs and cats can also carry *Strep. agalactiae* and MRSA, but the strains affecting dogs and cats are more closely related to human strains than bovine strains, at least for *Strep. agalactiae* (Yildirim et al., 2002).

### Nonmastitis Pathogens

“Diseases are bought and paid for” (Geart Benedictus, Benedictus Consulting, Joure, the Netherlands; personal observation): The most important route of introduction of infections is through purchase of infected animals. Although this is or should be common knowledge, many North American dairy farmers purchase animals on a regular basis (Wells, 2000; Hoe and Ruegg, 2006). Not many of these animals are screened for infectious diseases before or shortly after arrival at the dairy farm (Faust et al., 2001; Hoe and Ruegg, 2006). Also, quarantine is very difficult on most dairy farms and therefore seldom implemented (Faust et al., 2001; Villarroel et al., 2007). Purchase of animals is not the only route of introduction of infections. Replacement heifers that return from calf-rearing facilities where they have commingled with animals from other farms and animals returning from cattle shows or fairs can be an important source as well (Villarroel et al., 2007). Most farmers take insufficient measures to prevent spread of infections from animals returning from a calf-rearing facility or after a show (Thunes and Carpenter, 2007; Villarroel et al., 2007).

A few on-farm tests for infectious agents and antibodies have become available. For example, reliable rapid tests for BVDV, such as an antigen capture ELISA, make it feasible to identify persistently infected animals before they are mingled with the rest of the herd (Fulton et al., 2006). Also, an electronic nose (gas sensor array) was effective in detection of *Mycobacterium bovis* infection in cattle and other species (Fend et al., 2005) and in detection of mastitis pathogens (Hettinga et al., 2008). Additionally, tests such as multiplex PCR that will detect a large number of infectious agents may become available for routine or on-farm use in the future (e.g., Lenhoff et al., 2008).

Humans visiting farms can transfer infectious organisms. Individuals who visit many farms per day, such as inseminators and veterinarians, pose a high risk of introducing infections and should be instructed to wear protective clothing before handling cattle (Van Schaik et al., 2002). Transmission by humans played a significant role in the 2001 FMD outbreak and the 1997-1998 classical swine fever outbreak in the Netherlands (Stegeman et al., 1999; Bouma et al., 2003). Other important modes of transmission are through manure, equipment, cattle traders, and transportation trucks (e.g., Veling et al., 2002; Villarroel et al., 2007). If

dead stock is collected, collection vehicles should not be allowed to reach the proximity of the farm livestock.

Other animals, both domestic and wildlife, can also play an important role in transmission of infections between and within herds. It is good practice to keep dogs and cats away from dairy cattle to prevent transmission of pathogens and diseases, including *Neospora caninum* (Dijkstra et al., 2002; Bartels et al., 2007), echinococcosis/hydatidosis (Craig and Larrieu, 2006), *Toxoplasma gondii* (Canada et al., 2002), brucellosis (Mishal et al., 1999), leptospirosis (Leal-Castellanos et al., 2003), and rabies (Blancou, 2008). Wild canidae also play a role in the transmission of *N. caninum*, badgers can carry bovine tuberculosis, and deer can have BVDV, BHV-1, and FMD virus (Lamontagne et al., 1989; Máirtín et al., 1997; Dijkstra et al., 2002; Haigh et al., 2002; Olde Riekerink et al., 2005; Wapenaar et al., 2006). In outbreaks, however, the role of wildlife is sometimes suspected rather than proven, and the possibility of transmission by other species may be over-emphasized at the expense of not evaluating and addressing other more probable and important routes of transmission between and within cattle herds.

## PREVENTION OF ON-FARM TRANSMISSION

### Mastitis Pathogens

An important aspect of the control of infection, intramammary or otherwise, consists of preventing contagious transmission between animals within the herd. As stated by Dinsmore (2002): “40 years of knowledge regarding the on-farm control of contagious mastitis (now known as within-herd biosecurity) must be dusted off and implemented with renewed vigor to prevent the rampant spread of contagious mastitis.” In some countries, such as the UK and New Zealand, “environmental” mastitis is more prevalent than “contagious” mastitis, but overemphasis on environmental mastitis may carry the danger of neglecting basic control procedures for contagious transmission of pathogens, including those that may spread via the environment as well as from animal to animal (Bradley et al., 2007; Zadoks, 2007).

The foundation for the control of contagious mastitis on dairy farms was laid in the UK in the late 1960s (Neave et al., 1969). It led to development of the 5-point plan, which can be summarized as the combination of 1) good husbandry and milking practice with regular maintenance of the milking machine; 2) use of post-milking teat disinfection; 3) antimicrobial treatment of cows with clinical mastitis; 4) blanket dry cow treatment with antimicrobials; and 5) culling of chronically infected cows (Hillerton et al., 1995). The milking machine and milking technique affect the susceptibility of the mammary gland to infection as well as the risk of exposure to mastitis pathogens. It is important that all milkers, whether routine or relief staff, maintain correct operation of the machine (Grindal, 1988). Many studies have demonstrated the impact of post-milking teat disinfection on prevention of mastitis, including mastitis caused by *Staphylococcus* and *Streptococcus* species (NMC, 2008). Treatment of clinical or subclinical mastitis may contribute to reduced transmission of infection, but antimicrobial treatment of mastitis is not always successful (Barkema et al., 2006; Zadoks, 2007). When treatment fails, removal of the infected animal from the herd to prevent contagious transmission may be necessary. Routine treatment of all cows with antimicrobials at dry off is criticized out of concern over development of antimicrobial resistance, but a recent meta-analysis showed that the risk of new IMI is 1.5 to 1.9 times as high in quarters or cows that do not receive blanket dry cow treatment as in cows that do receive blanket dry cow treatment (Robert et al., 2006).

Despite longstanding recognition of the importance of the milking machine in mastitis prevention, more than 60% of parlors failed their annual performance test in a 2004 survey

of 1,000 herds in the UK (Berry et al., 2005). Compared with farms with low BMSCC, farms with high BMSCC less frequently use blanket dry cow treatment and post-milking teat disinfection and treat clinical mastitis cows for a relatively short time (Erskine et al., 1987; Barkema et al., 1999b). Additionally, several recommended procedures are practiced more often on low BMSCC farms (i.e., regular check of milking machine, dry udder preparation, hygiene management) than on farms with a higher BMSCC (Barkema et al., 1999b). These findings underscore the need to “dust off” our existing knowledge on control of mastitis. Although knowledge is available, some farmers do not implement it, in part because they fail to see its economic value (Huijps et al., 2008). Compliance with preventive strategies is linked to the producer’s attitude (Barkema et al., 1999a), the level of encouragement for application of control measures (Zadoks et al., 2002; Hillerton et al., 1995) and to the degree of success in mastitis control achieved (Green et al., 2007b). Penalties for high BMSCC seem to be the only measure to convince these farmers to implement the basics of control of contagious mastitis. In some cases, BMSCC is manipulated by withholding milk from cows from the bulk supply and by culling rather than through implementation of disease control measures.

Transmission of contagious mastitis pathogens mainly occurs during milking (Fox and Gay, 1993). To ensure that every milking starts with milking equipment that is not contaminated with pathogens, the use of a “disinfecting” milking machine wash-up routine after every milking is strongly recommended (<http://www.nmconline.org/docs/NMCchecklistInt.pdf>). It is important to adhere to a milking order (infection-free animals first; infected animals last) in herds with a high or increasing BMSCC (Wilson et al., 1995). This is simplest to implement in a tie-stall herd. In large free-stall herds, it is preferable to milk heifers before older animals and healthy animals before the sick pen, because the risk of presence of infection tends to increase in that order (Villarreal et al., 2007). Isolation of infected animals is also very important in *Mycoplasma* mastitis outbreaks (González and Wilson, 2003). Segregation of cows with clinical mastitis or high SCC and proper use of the sick pen (i.e., no use of the sick pen as a calving pen) are additional proven measures to prevent new IMI (Wilson et al., 1995). Consideration should be given to housing heifers separately from older cows (McDougall et al., 2008), particularly the sick ones. The role of waste milk in transmission of *Staph. aureus* mastitis is poorly understood. It does not appear to contribute to mastitis when calves are reared in isolation, but when there is opportunity for cross-suckling among animals or transmission by flies, waste milk may act as a source of mastitis pathogens (Roberson et al., 1994). Although it may appear economically attractive or “natural,” waste milk should not be fed to calves because it can be contaminated with pathogens such as MAP or *Mycoplasma* (González and Wilson, 2003; Ruzante et al., 2008). Pasteurization of waste milk reduces the risk of pathogen transmission when performed properly, but it does not eliminate the risk of transmission of MAP because the organism can survive pasteurization (Ruzante et al., 2008).

For monitoring of on-farm transmission of mastitis, as for assessment of the health status of animals that are introduced into the herd, data and samples at the group or animal level can be used. Bulk milk monitoring can be used to detect mastitis pathogens such as *Strep. agalactiae*, *Staph. aureus*, and *Mycoplasma*. Because the sensitivity of single bulk milk culture is limited, longitudinal monitoring is necessary to achieve high herd-level sensitivity of pathogen detection (Fox et al., 2005; Olde Riekerink et al., 2006). In large herds, in-line sampling of groups of animals or string sampling of the sick pen can be used for monitoring purposes (Dinsmore, 2002; Godden et al., 2002). At the cow level, clinical mastitis and SCC indices must be monitored (Bradley and Green, 2005; Bradley et al., 2008). Modern software is now available to provide easy access to such analysis (e.g., [www.dairyone.com/DairyManagementResources/DairyComp305/default.htm](http://www.dairyone.com/DairyManagementResources/DairyComp305/default.htm); [www.qmms.co.uk/software](http://www.qmms.co.uk/software); and [www.total-vet.co.uk](http://www.total-vet.co.uk)). Culture of milk samples from cows with clinical or subclinical

mastitis allows for identification of causative agents, monitoring of transmission, and selection of animals as candidates for treatment, segregation, or culling.

Although the focus of this article is mainly contagious transmission, it is important to be mindful of the considerable importance of the environmental reservoir of mastitis pathogens. Components of herd and environmental management both during lactation (Barkema et al., 1999c; O'Reilly et al., 2006; Pyörälä, 2008) and during the dry period and calving period (Green et al., 2007a, 2008; <http://www.nmconline.org/docs/NMC-checklistInt.pdf>) are vital in mastitis control.

### Nonmastitis Pathogens

Prevalence of infectious diseases is driven by their incidence and the duration of infections. In the case of contagious diseases, reduction in the duration of infections will also result in reduced exposure of herd mates and hence in reduced incidence. To limit the duration of infection, infections must be detected through the use of diagnostics tests, and test results must be used for treatment or culling decisions.

Presence of several infectious agents that have an indirect effect on mastitis, such as BVDV, can be monitored using bulk milk (Houe et al., 2006). Furthermore, antibodies against a range of bacteria, protozoa, and viruses such as *N. caninum*, BHV-1, *Salmonella* spp., *Leptospira hardjo*, and bovine leukemia virus can be detected using this medium (e.g., Wapenaar et al., 2007). For other pathogens such as MAP, sensitivity of tests conducted on bulk milk is limited (Jayarao et al., 2004). Adjustments in interpretative criteria for ELISA results (Van Weering et al., 2007) or use of real-time PCR (Herthnek et al., 2008) may increase the sensitivity of detection for Johne's disease. When a group of animals is found to be positive based on herd- or string-level tests, subsequent animal-level tests can be used to identify infected animals. Bulk tank testing will not provide information on the infection status of dry cows, young stock, or nulliparous heifers, and separate monitoring of those groups may be necessary. Diseased animals should be seen as potential indicators of herd-level problems and their infection status should be monitored (Dinsmore, 2002). In the context of udder health, this is obvious for cows with clinical mastitis or high SCC. It also applies to animals showing other symptoms, such as diarrhea or abortion, which may be associated with infectious diseases that affect udder health indirectly.

Once infections are diagnosed, their duration may be limited through treatment (e.g., in the case of many mastitis pathogens) or through culling (e.g., in animals that are persistently infected with BVDV or infected with MAP). When infections are self-limiting, such as in cases of salmonellosis, treatment is not effective and culling is not necessary, but animals shedding the pathogen should be segregated from other animals until shedding has ceased. Biosecurity practices, especially those focused on sick cow management, calving area management, and manure management, limit the transmission of pathogens within an infected dairy operation (Wells, 2000; Villarroel et al., 2007). In addition, disease-specific monitoring and control programs have been developed, for example, for BVD (Moennig et al., 2005), MAP (Groenendaal et al., 2003; McKenna et al., 2006a), and salmonellosis (Warnick et al., 2006). For some contagious diseases, such as *Staph. aureus* mastitis, BVD, leptospirosis, and neosporosis, vaccines are available in some countries. Vaccination is usually considered an adjunct rather than an alternative to other control methods (Grooms, 2006; Dubey et al., 2007; Middleton et al., 2009).

### THE FUTURE

The approach to control of infectious diseases differs between Europe, Australia, and New Zealand on one side and North America on the other side. Prevention and control of

infectious diseases is not yet the most important concern for emerging dairy nations such as India and China. In South America, *Strep. agalactiae* is still common (Duarte et al., 2004; Denamiel et al., 2005), suggesting relatively low levels of between- and within-herd biosecurity. In some nascent dairy industries (e.g., Colombia), cow-level SCC is not measured at all and bacterial counts exceed the average SCC of many other countries. Incentives for investment in biosecurity, including availability and use of diagnostic facilities, differ between countries (Windsor, 2002) and are dependent on factors such as the importance of export, level of self-sufficiency within a country, national or industry limits for bulk milk SCC, and premium and penalty payments relative to the base milk price.

Tracing the spread of new infections on a regional or national level is only possible if animals are properly identified, and animal traffic is monitored. An identification and registration (I&R) system for cattle is mandatory in most European countries, Canada, New Zealand, Australia, and Japan. When a foreign animal disease outbreak such as FMD occurs, it is nearly impossible to trace all cattle movements without a proper identification and registration system (Nielen et al., 1996). In the European Union, the system has proven its value in a large number of outbreaks of foreign animal disease. The Canadian Cattle Identification Program has proven its value in the North American BSE “outbreak.” A shift from external identification devices such as ear tags to more advanced devices such as injectable transponders can be expected. At the pathogen level, strain typing is increasingly used to monitor routes of disease transmission within and between herds, countries, and continents (Zadoks and Schukken, 2006).

Because of improvements in technology, our ability to trace animals and pathogens has increased dramatically in recent years and so has the ability to share information. Information sharing can contribute to disease control and to consumer awareness of animal diseases. In some countries, the need to trace pathogens, animals, and food of animal origin has increased, largely because of consumer concerns about animal health and welfare and food quality and safety. In other parts of the world, the growing size or increasing purchasing power of the population is generating an urgent need for quantity rather than quality of milk and dairy products. As international trade and travel increase, the risk of disease introduction and the importance of a disease-free status of animal populations will increase. Biosecurity has always been important for a farm’s profitability and the health of its animals. In addition, efficient use of limited resources is increasingly important because of the growth of the world population and increasing demands on available land mass for agriculture, fuel production, and other uses. Healthy animals produce more efficiently than unhealthy animals, and thus biosecurity contributes to efficient resource utilization (Zadoks and Fitzpatrick, 2009). Because of globalization and heightened consumer awareness, the importance of biosecurity now supersedes the individual farm level, and increased pressure to control transmission of infectious diseases can be expected at industry or government levels in western countries. The balance between population growth and increased individual wealth in other parts of the world may determine the extent to which other countries follow suit.

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## REFERENCES

- Andersen HJ, Pedersen LH, Aarestrup FM, Chriél M. Evaluation of the surveillance program of *Streptococcus agalactiae* in Danish dairy herds. *J. Dairy Sci.* 2003; 86:1233–1239. [PubMed: 12741548]



- Barkema HW, Schukken YH, Lam TJGM, Beiboer ML, Benedictus G, Brand A. Management practices associated with low, medium, and high somatic cell counts in bulk milk. *J. Dairy Sci.* 1999b; 81:1917–1927. [PubMed: 9710760]
- Barkema HW, Schukken YH, Lam TJGM, Beiboer ML, Benedictus G, Brand A. Management practices associated with the incidence rate of clinical mastitis. *J. Dairy Sci.* 1999c; 82:1643–1654. [PubMed: 10480089]
- Barkema HW, Schukken YH, Zadoks RN. Invited review: The role of cow, pathogen, and treatment regimen in the therapeutic success of bovine *Staphylococcus aureus* mastitis. *J. Dairy Sci.* 2006; 89:1877–1895. [PubMed: 16702252]
- Barkema HW, van der Ploeg JD, Schukken YH, Lam TJ, Benedictus G, Brand A. Management style and its association with bulk milk somatic cell count and incidence rate of clinical mastitis. *J. Dairy Sci.* 1999a; 82:1655–1663. [PubMed: 10480090]
- Bartels CJ, Huinink I, Beiboer ML, van Schaik G, Wouda W, Dijkstra T, Stegeman A. Quantification of vertical and horizontal transmission of *Neospora caninum* infection in Dutch dairy herds. *Vet. Parasitol.* 2007; 148:83–92. [PubMed: 17640807]
- Beaudeau F, Fourichon C, Robert A, Joly A, Seegers H. Bulk milk somatic cell counts and bovine viral diarrhoea virus (BVDV) infection in 7252 dairy herds in Brittany (western France). *Prev. Vet. Med.* 2005; 72:163–167. [PubMed: 16169615]
- Berends IMGA, Swart WAJM, Frankena K, Muskens J, Lam TJGM, van Schaik G. The effect of becoming BVDV-free on fertility and udder health in Dutch dairy herds. *Prev. Vet. Med.* 2008; 84:48–60. [PubMed: 18155307]
- Berry EA, Scrivens M, Hillerton JE. Milking machine test survey of UK herds. *Vet. Rec.* 2005; 157:147–148. [PubMed: 16055663]
- Biddle MK, Fox LK, Hancock DD. Patterns of mycoplasma shedding in the milk of dairy cows with intramammary mycoplasma infection. *J. Am. Vet. Med. Assoc.* 2003; 223:1163–1166. [PubMed: 14584748]
- Blancou J. The control of rabies in Eurasia: Overview, history and background. *Dev. Biol. (Basel).* 2008; 131:3–15. [PubMed: 18634461]
- Borm AA, Fox LK, Leslie KE, Hogan JS, Andrews SM, Moyes KM, Oliver SP, Schukken YH, Hancock DD, Gaskins CT, Owens WE, Norman C. Effects of prepartum intramammary antibiotic therapy on udder health, milk production, and reproductive performance in dairy heifers. *J. Dairy Sci.* 2006; 89:2090–2098. [PubMed: 16702275]
- Bouma A, Elbers AR, Dekker A, de Koeijer A, Bartels C, Vellema P, van der Wal P, van Rooij EM, Pluimers FH, de Jong MC. The foot-and-mouth epidemic in The Netherlands in 2001. *Prev. Vet. Med.* 2003; 57:155–166. [PubMed: 12581598]
- Bradley AJ, Breen JE, Green ME. Mastitis pattern analysis - A fresh look at the analysis of bovine mastitis: Part 2 - Clinical mastitis data. *UK Vet. (Livestock).* 2008; 13:1–5.
- Bradley AJ, Green MJ. Adaptation of *Escherichia coli* to the bovine mammary gland. *J. Clin. Microbiol.* 2001; 39:1845–1849. [PubMed: 11326001]
- Bradley AJ, Green MJ. Use and interpretation of somatic cell count data in dairy cows. In *Pract.* 2005; 27:310–315.
- Bradley AJ, Leach KA, Breen JE, Green LE, Green ME. Survey of the incidence and aetiology of mastitis on dairy farms in England and Wales. *Vet. Rec.* 2007; 160:253–257. [PubMed: 17322356]
- Brolund L. Cell counts in bovine milk: Causes of variation and applicability for diagnosis of subclinical mastitis. *Acta Vet. Scand.* 1985; 80:1–123.
- Canada N, Meireles CS, Rocha A, da Costa JM, Erickson MW, Dubey JP. Isolation of viable *Toxoplasma gondii* from naturally infected aborted bovine fetuses. *J. Parasitol.* 2002; 88:1247–1248. [PubMed: 12537120]
- Cannas da Silva J, Noordhuizen JP, Vagneur M, Bexiga R, Gelfert CC, Baumgartner W. Veterinary dairy herd health management in Europe: Constraints and perspectives. *Vet. Q.* 2006; 28:23–32. [PubMed: 16605158]
- Carrique-Mas JJ, Medley GF, Green LE. Risks for bovine tuberculosis in British cattle farms restocked after the foot and mouth disease epidemic of 2001. *Prev. Vet. Med.* 2008; 84:85–93. [PubMed: 18164499]

- Craig PS, Larrieu E. Control of echinococcosis/hydatidosis: 1863-2002. *Adv. Parasitol.* 2006; 61:443–508. [PubMed: 16735171]
- Denamiel G, Llorente P, Carabella M, Rebuelto M, Gentilini E. Anti-microbial susceptibility of *Streptococcus* spp. isolated from bovine mastitis in Argentina. *J. Vet. Med. B Infect. Dis. Vet. Public Health.* 2005; 52:125–128. [PubMed: 15876224]
- Devriese LA, Hommez J. Epidemiology of methicillin-resistant *Staphylococcus aureus* in dairy herds. *Res. Vet. Sci.* 1975; 19:23–27. [PubMed: 125447]
- Diéguez FJ, Arnaiz I, Sanjuán ML, Vilar MJ, Yus E. Management practices associated with *Mycobacterium avium* subspecies *paratuberculosis* infection and the effects of the infection on dairy herds. *Vet. Rec.* 2008; 162:614–617. [PubMed: 18480020]
- Dijkstra, Th.; Barkema, HW.; Hesselink, JW.; Wouda, W. Natural transmission routes of *Neospora caninum* between farm dogs and cattle. *Vet. Parasitol.* 2002; 105:99–104. [PubMed: 11900923]
- Dinsmore RP. Biosecurity for mammary diseases in dairy cattle. *Vet. Clin. North Am. Food Anim. Pract.* 2002; 18:115–131. [PubMed: 12064164]
- Dohoo IR, Meek AH. Somatic cell counts in bovine milk. *Can. Vet. J.* 1982; 23:119–125. [PubMed: 17422127]
- Duarte RS, Miranda OP, Bellei BC, Brito MA, Teixeira LM. Phenotypic and molecular characteristics of *Streptococcus agalactiae* isolates recovered from milk of dairy cows in Brazil. *J. Clin. Microbiol.* 2004; 42:4214–4222. [PubMed: 15365014]
- Dubey JP, Schares G, Ortega-Mora LM. Epidemiology and control of neosporosis and *Neospora caninum*. *Clin. Microbiol. Rev.* 2007; 20:323–367. [PubMed: 17428888]
- Erskine RJ, Eberhart RJ, Hutchinson LJ, Spencer SB. Herd management and prevalence of mastitis in dairy herds with high and low somatic cell counts. *J. Am. Vet. Med. Assoc.* 1987; 190:1411–1416. [PubMed: 3301762]
- Erskine RJ, Walker RD, Bolin CA, Bartlett PC, White DG. Trends in antibacterial susceptibility of mastitis pathogens during a seven-year period. *J. Dairy Sci.* 2002; 85:1111–1118. [PubMed: 12086045]
- FAO. Accessed April 30, 2009 Global Rinderpest Eradication Programme (GREP). 2009 <http://www.fao.org/ag/againfo/programmes/en/grep/home.html>
- Faust MA, Kinsel ML, Kirkpatrick MA. Characterizing biosecurity, health, and culling during dairy herd expansions. *J. Dairy Sci.* 2001; 84:955–965. [PubMed: 11352173]
- Fend R, Geddes R, Lesellier S, Vordermeier HM, Corner LA, Gormley E, Costello E, Hewinson RG, Marlin DJ, Woodman AC, Chambers MA. Use of an electronic nose to diagnose *Mycobacterium bovis* infection in badgers and cattle. *J. Clin. Microbiol.* 2005; 43:1745–1751. [PubMed: 15814995]
- Fox LK. Prevalence, incidence and risk factors of heifer mastitis. *Vet. Microbiol.* 2009; 134:82–88. [PubMed: 18930610]
- Fox LK, Gay JM. Contagious mastitis. *Vet. Clin. North Am. Food Anim. Pract.* 1993; 9:475–487. [PubMed: 8242453]
- Fox LK, Kirk JH, Britten A. *Mycoplasma* mastitis: A review of transmission and control. *J. Vet. Med. B Infect. Dis. Vet. Public Health.* 2005; 52:153–160. [PubMed: 16000109]
- Fulton RW, Hessman B, Johnson BJ, Ridpath JF, Saliki JT, Burge LJ, Sjeklocha D, Confer AW, Funk RA, Payton ME. Evaluation of diagnostic tests used for detection of bovine viral diarrhoea virus and prevalence of subtypes 1a, 1b, and 2a in persistently infected cattle entering a feedlot. *J. Am. Vet. Med. Assoc.* 2006; 228:578–584. [PubMed: 16478438]
- Gillespie BE, Headrick SI, Boonyayatra S, Oliver SP. Prevalence and persistence of coagulase-negative *Staphylococcus* species in three dairy research herds. *Vet. Microbiol.* 2009; 134:65–72. [PubMed: 18950962]
- Godden S, Bey R, Farnsworth R, Reneau J, Lavalley M. Field validation of a milk line sampling device for monitoring milk quality and udder health. *J. Dairy Sci.* 2002; 85:1468–1475. [PubMed: 12146478]
- González RN, Wilson DJ. Mycoplasmal mastitis in dairy herds. *Vet. Clin. North Am. Food Anim. Pract.* 2003; 19:199–221. [PubMed: 12682943]

- Green MJ, Bradley AJ, Medley GF, Browne WJ. Cow, farm and management factors during the dry period that determine the rate of clinical mastitis after calving. *J. Dairy Sci.* 2007a; 90:3764–3776. [PubMed: 17638988]
- Green MJ, Bradley AJ, Medley GF, Browne WJ. Cow, farm and herd management factors in the dry period risk associated with raised somatic cell counts in early lactation. *J. Dairy Sci.* 2008; 91:1403–1415. [PubMed: 18349232]
- Green MJ, Leach KA, Breen JE, Green LE, Bradley AJ. A national intervention study of mastitis control on dairy herds in England and Wales. *Vet. Rec.* 2007b; 160:287–293. [PubMed: 17337605]
- Grindal RJ. The role of the milking machine in mastitis. *Br. Vet. J.* 1988; 144:524–533. [PubMed: 3203203]
- Groenendaal H, Nielen M, Hesselink JW. Development of the Dutch Johne's disease control program supported by a simulation model. *Prev. Vet. Med.* 2003; 60:69–90. [PubMed: 12900150]
- Grooms DL. Reproductive losses caused by bovine viral diarrhea virus and leptospirosis. *Theriogenology.* 2006; 66:624–628. [PubMed: 16716386]
- Gunn GJ, Heffernan C, Hall M, McLead A, Hovi M. Measuring and comparing constraints to improved biosecurity amongst GB farmers, veterinarians and the auxiliary industries. *Prev. Vet. Med.* 2008; 84:310–323. [PubMed: 18282623]
- Hadley GL, Wolf CA, Harsh SB. Dairy cattle culling patterns, explanations, and implications. *J. Dairy Sci.* 2006; 89:2286–2296. [PubMed: 16702296]
- Haigh JC, Mackintosh C, Griffin F. Viral, parasitic and prion diseases of farmed deer and bison. *Rev. Sci. Tech.* 2002; 21:219–248. [PubMed: 11974612]
- Hassan AA, Akineden O, Usleber E. Identification of *Streptococcus canis* isolated from milk of dairy cows with subclinical mastitis. *J. Clin. Microbiol.* 2005; 43:1234–1238. [PubMed: 15750089]
- Herthnek D, Nielsen SS, Lindberg A, Bölske G. A robust method for bacterial lysis and DNA purification to be used with real-time PCR for detection of *Mycobacterium avium* subsp. *paratuberculosis* in milk. *J. Microbiol. Methods.* 2008; 75:335–340. [PubMed: 18694788]
- Hettinga KA, van Valenberg HJ, Lam TJ, van Hoijsdonk AC. Detection of mastitis pathogens by analysis of volatile bacterial metabolites. *J. Dairy Sci.* 2008; 91:3834–3839. [PubMed: 18832205]
- Hillerton JE, Bramley AJ, Staker RT, McKinnon CH. Patterns of intramammary infection and clinical mastitis over a 5 year period in a closely monitored herd applying mastitis control measures. *J. Dairy Res.* 1995; 62:39–50. [PubMed: 7738244]
- Hillerton JE, Leigh JA, Ward PN, Coffey TJ. *Streptococcus agalactiae* infections in dairy cows. *Vet. Rec.* 2004; 154:671–672. [PubMed: 15198320]
- Hoe FG, Ruegg PL. Opinions and practices of Wisconsin dairy producers about biosecurity and animal well-being. *J. Dairy Sci.* 2006; 89:2297–2308. [PubMed: 16702297]
- Houe H, Lindberg A, Moennig V. Test strategies in bovine viral diarrhea virus control and eradication campaigns in Europe. Test strategies in bovine viral diarrhea virus control and eradication campaigns in Europe. *J. Vet. Diagn. Invest.* 2006; 18:427–436. [PubMed: 17037609]
- Huijps K, Lam TJ, Hogeveen H. Costs of mastitis: Facts and perception. *J. Dairy Res.* 2008; 75:113–120. [PubMed: 18226298]
- Jayarao BM, Pillai SR, Wolfgang DR, Griswold DR, Rossiter CA, Tewari D, Burns CM, Hutchinson LJ. Evaluation of IS900-PCR assay for detection of *Mycobacterium avium* subspecies *paratuberculosis* infection in cattle using quarter milk and bulk tank milk samples. *Foodborne Pathog. Dis.* 2004; 1:17–26. [PubMed: 15992258]
- Juhász-Kaszanyitzky E, Jánosi S, Somogyi P, Dán A, van der Graaf-van Blooi L, van Duinkerken E, Wagenaar JA. MRSA transmission between cows and humans. *Emerg. Infect. Dis.* 2007; 13:630–632. [PubMed: 17553285]
- Kálmán D, Jánosi S, Egyed L. Role of bovine herpesvirus 4 in bacterial bovine mastitis. *Microb. Pathog.* 2004; 37:125–129. [PubMed: 15351035]
- Lamontagne L, Sadi L, Joyal R. Serological evidence of bovine herpesvirus 1-related virus infection in the white-tailed deer population on Anticosti Island, Quebec. *J. Wildl. Dis.* 1989; 25:202–205. [PubMed: 2541261]

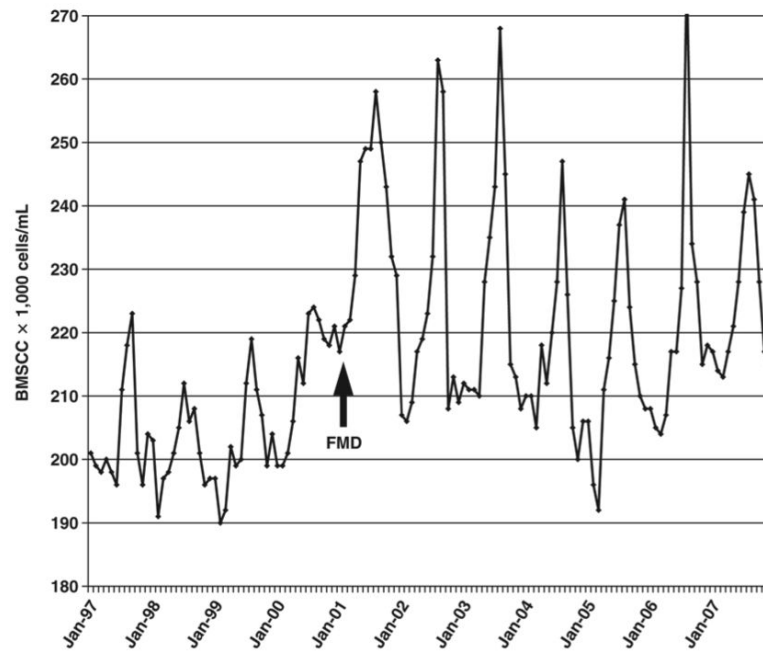
- Leal-Castellanos CB, García-Suárez R, González-Figueroa E, Fuentes-Allen JL, Escobedo-de la Peñal J. Risk factors and the prevalence of leptospirosis infection in a rural community of Chiapas, Mexico. *Epidemiol. Infect.* 2003; 131:1149–1156. [PubMed: 14959783]
- Lee JH. Methicillin (oxacillin)-resistant *Staphylococcus aureus* strains isolated from major food animals and their potential transmission to humans. *Appl. Environ. Microbiol.* 2003; 69:6489–6494. [PubMed: 14602604]
- Leedom JM. Milk of nonhuman origin and infectious diseases in humans. *Clin. Infect. Dis.* 2006; 43:610–615. [PubMed: 16886155]
- Lenhoff RJ, Naraghi-Arani P, Thissen JB, Olivas J, Carillo AC, Chinn C, Rasmussen M, Messenger SM, Suer LD, Smith SM, Tammero LF, Vitalis EA, Slezak TR, Hullinger PJ, Hindson BJ, Hietala SK, Crossley BM, McBride MT. Multiplexed molecular assay for rapid exclusion of foot-and-mouth disease. *J. Virol. Methods.* 2008; 153:61–69. [PubMed: 18634827]
- Loeffler SH, Lam TJ, Barkema HW, Scholten D, Hessels AL, van Gestel AM. The dairying veterinary approach to a high bulk milk cell count caused by *Streptococcus agalactiae*. *Tijdschr. Diergeneesk.* 1995; 120:458–463.
- Máirtín DO, Williams DH, Griffin JN, Dolan LA, Eves JA. The effect of a badger removal programme on the incidence of tuberculosis in an Irish cattle population. *Prev. Vet. Med.* 1997; 34:47–56.
- Makovec JA, Ruegg PL. Antimicrobial resistance of bacteria isolated from dairy cow milk samples submitted for bacterial culture: 8,905 samples (1994–2001). *J. Am. Vet. Med. Assoc.* 2003; 222:1582–1589. [PubMed: 12784967]
- McDougall S, Parker KI, Heuer C, Compton CW. A review of prevention and control of heifer mastitis via non-antibiotic strategies. *Vet. Microbiol.* 2008; 134:177–185. [PubMed: 18986782]
- McKenna SLB, Keefe GP, Barkema HW, McClure J, Vanleeuwen JA, Hanna P, Sockett DC. Cow-level prevalence of paratuberculosis in culled dairy cows in Atlantic Canada and Maine. *J. Dairy Sci.* 2004; 87:3770–3777. [PubMed: 15483160]
- McKenna SLB, Keefe GP, Tiwari A, VanLeeuwen J, Barkema HW. Johne's disease in Canada. Part II: Disease impacts, risk factors, and control programs for dairy producers. *Can. Vet. J.* 2006b; 47:1089–1099. [PubMed: 17147140]
- McKenna SLB, VanLeeuwen JA, Barkema HW, Jansen JT, Hauer G, Hendrick SH, Coté G, Empringham RE. A proposed Canadian voluntary Johne's disease prevention and control program. *Can. Vet. J.* 2006a; 47:539–541. [PubMed: 16808225]
- Middleton JR, Fox LK, Gay JM, Tyler JW, Besser TE. Use of pulsed-field gel electrophoresis for detecting differences in *Staphylococcus aureus* strain populations between dairy herds with different cattle importation practices. *Epidemiol. Infect.* 2002; 129:387–395. [PubMed: 12403115]
- Middleton JR, Luby CD, Adams DS. Efficacy of vaccination against staphylococcal mastitis: A review and new data. *Vet. Microbiol.* 2009; 134:192–198. [PubMed: 19010613]
- Mishal J, Ben-Israel N, Levin Y, Sherf S, Jafari J, Embon E, Sherer Y. Brucellosis outbreak: Analysis of risk factors and serologic screening. *Int. J. Mol. Med.* 1999; 4:644–658.
- Moennig V, Houe H, Lindberg A. BVD control in Europe: Current status and perspectives. *Anim. Health Res. Rev.* 2005; 6:63–74. [PubMed: 16164009]
- Moon JS, Lee AR, Kang HM, Lee ES, Kim MN, Paik YH, Park YH, Joo YS, Koo HC. Phenotypic and genetic antibiogram of methicillin-resistant staphylococci isolated from bovine mastitis in Korea. *J. Dairy Sci.* 2007; 90:1176–1185. [PubMed: 17297092]
- Muñoz MA, Welcome FL, Schukken YH, Zadoks RN. Molecular epidemiology of two *Klebsiella pneumoniae* mastitis outbreaks on a dairy farm in New York State. *J. Clin. Microbiol.* 2007; 45:3964–3971. [PubMed: 17928424]
- Murinda SE, Nguyen LT, Nam HM, Almeida RA, Headrick SJ, Oliver SP. Detection of sorbitol-negative and sorbitol-positive Shiga toxin-producing *Escherichia coli*, *Listeria monocytogenes*, *Campylobacter jejuni*, and *Salmonella* spp. in dairy farm environmental samples. *Foodborne Pathog. Dis.* 2004; 1:97–104. [PubMed: 15992268]
- Neave FK, Dodd FH, Kingwill RG, Westgarth DR. Control of mastitis in the dairy herd by hygiene and management. *J. Dairy Sci.* 1969; 52:696–707. [PubMed: 5391057]
- Nickerson SC. Control of heifer mastitis: Antimicrobial treatment - An overview. *Vet. Microbiol.* 2009; 134:128–135. [PubMed: 18963599]

- Nielen M, Jansen FC, van Wuijckhuise LA, Dijkhuizen AA. I&R (identification and registration) system cattle: An analysis of its use during a foot-and-mouth-disease outbreak in The Netherlands. *Tijdschr. Diergeneeskd.* 1996; 121:576–581. [PubMed: 8966704]
- Nielsen LR, Ersbøll AK. Factors associated with variation in bulk-tank-milk *Salmonella* Dublin ELISA ODC% in dairy herds. *Prev. Vet. Med.* 2005; 68:165–179. [PubMed: 15820114]
- Nielsen LR, Warnick LD, Greiner M. Risk factors for changing test classification in the Danish surveillance program for *Salmonella* in dairy herds. *J. Dairy Sci.* 2007; 90:2815–2825. [PubMed: 17517722]
- Nielsen SS, Toft N. A review of prevalences of paratuberculosis in farmed animals in Europe. *Prev. Vet. Med.* 2009; 88:1–14. [PubMed: 18817995]
- Nightingale C, Dhuyvetter K, Mitchell R, Schukken Y. Influence of variable milk quality premiums on observed milk quality. *J. Dairy Sci.* 2008; 91:1236–1244. [PubMed: 18292282]
- Nightingale KK, Fortes ED, Ho AJ, Schukken YH, Gröhn YT, Wiedmann M. Evaluation of farm management practices as risk factors for clinical listeriosis and fecal shedding of *Listeria monocytogenes* in ruminants. *J. Am. Vet. Med. Assoc.* 2005; 227:1808–1814. [PubMed: 16350271]
- NMC. Accessed April 30, 2008 Summary of peer-reviewed publications on efficacy of premilking and postmilking teat disinfectant published since 1980. 2008 <http://www.nmconline.org/docs/Teatbibl.pdf>
- O'Reilly KM, Green MJ, Peeler EJ, Fitzpatrick JL, Green LE. Investigation of risk factors for clinical mastitis in British dairy herds with bulk milk somatic cell counts less than 150,000 cells/ml. *Vet. Rec.* 2006; 158:649–653. [PubMed: 16699133]
- OIE. Accessed April 30, 2009 OIE listed diseases. 2006 [http://www.oie.int/eng/maladies/en\\_classification.htm](http://www.oie.int/eng/maladies/en_classification.htm)
- Olde Riekerink RG, Dominici A, Barkema HW, de Smit AJ. Seroprevalence of pestivirus in four species of Alpine wild ungulates in the High Valley of Susa, Italy. *Vet. Microbiol.* 2005; 108:297–303. [PubMed: 15922522]
- Olde Riekerink RGM, Barkema HW, Kelton DF, Scholl DT. Incidence rate of clinical mastitis on Canadian dairy farms. *J. Dairy Sci.* 2008; 91:1366–1377. [PubMed: 18349229]
- Olde Riekerink RGM, Barkema HW, Veenstra S, Poole DE, Dingwell RT, Keefe GP. Prevalence of contagious mastitis pathogens in bulk tank milk in Prince Edward Island. *Can. Vet. J.* 2006; 47:567–572. [PubMed: 16808229]
- Owens WE, Nipper WA. Accessed April 30, 2009 Case study: Development of a *Mycoplasma* mastitis control program in Louisiana. *Prof. Anim. Scientist.* 2008 on line [http://findarticles.com/p/articles/mi\\_qa4035/is\\_200802/ai\\_n24393806](http://findarticles.com/p/articles/mi_qa4035/is_200802/ai_n24393806)
- Piepers S, De Meulemeester L, de Kruif A, Opsomer G, Barkema HW, de Vliegher S. Prevalence and distribution of mastitis pathogens in subclinically infected dairy cows in Flanders, Belgium. *J. Dairy Res.* 2007; 74:478–483. [PubMed: 17931457]
- Pitkälä A, Haveri M, Pyörälä S, Myllys V, Honkanen-Buzalski T. Bovine mastitis in Finland 2001- Prevalence, distribution of bacteria, and antimicrobial resistance. *J. Dairy Sci.* 2004; 87:2433–2441. [PubMed: 15328265]
- Pyörälä S. Mastitis in post-partum dairy cows. *Reprod. Domest. Anim.* 2008; 43(Suppl. 2):252–259. [PubMed: 18638132]
- Roberson JR, Fox LK, Hancock DD, Gay JM, Besser TE. Ecology of *Staphylococcus aureus* isolated from various sites on dairy farms. *J. Dairy Sci.* 1994; 77:3354–3364. [PubMed: 7814712]
- Robert A, Seegers H, Bareille N. Incidence of intramammary infections during the dry period without or with antibiotic treatment in dairy cows—A quantitative analysis of published data. *Vet. Res.* 2006; 37:25–48. [PubMed: 16336923]
- Ruzante JM, Gardner IA, Cullor JS, Smith WL, Kirk JH, Adaska JM. Isolation of *Mycobacterium avium* subsp. *paratuberculosis* from waste milk delivered to California calf ranches. *Foodborne Pathog. Dis.* 2008; 5:681–686. [PubMed: 18681799]
- Sampimon O, Barkema HW, Sol J, Lam T. Prevalence of intramammary infection in Dutch dairy herds. *J. Dairy Res.* 2009; 76:129–136. [PubMed: 19121233]



- Sawant AA, Gillespie BE, Oliver SP. Antimicrobial susceptibility of coagulase-negative *Staphylococcus* species isolated from bovine milk. *Vet. Microbiol.* 2009; 134:73–81. [PubMed: 18950969]
- Schepers AJ, Lam TJGM, Schukken YH, Wilmink JBM, Hanekamp WJA. Estimation of variance of components for somatic cell counts to determine thresholds for uninfected quarters. *J. Dairy Sci.* 1997; 80:1833–1840. [PubMed: 9276824]
- Schukken YH, Wilson DJ, Welcome F, Garrison-Tikofsky L, González RN. Monitoring udder health and milk quality using somatic cell counts. *Vet. Res.* 2003; 34:579–596. [PubMed: 14556696]
- Sears PM, McCarthy KK. Management and treatment of staphylococcal mastitis. *Vet. Clin. North Am. Food Anim. Pract.* 2003; 19:171–185. [PubMed: 12682941]
- Smith TH, Fox LK, Middleton JR. Outbreak of mastitis caused by one strain of *Staphylococcus aureus* in a closed dairy herd. *J. Am. Vet. Med. Assoc.* 1998; 212:553–556. [PubMed: 9491165]
- Sordillo LM, Shafer-Weaver K, DeRosa D. Immunobiology of the mammary gland. *J. Dairy Sci.* 1997; 80:1851–1865. [PubMed: 9276826]
- Stegeman JA, Elbers ARW, Bouma A, de Smit H, de Jong MCM. Transmission of classical swine fever virus within herds during the 1997-1998 epidemic in The Netherlands. *Prev. Vet. Med.* 1999; 42:201–218. [PubMed: 10619156]
- Stup RE, Hyde J, Holden LA. Relationships between selected human resource management practices and dairy farm performance. *J. Dairy Sci.* 2006; 89:1116–1120. [PubMed: 16507709]
- Thompson D, Muriel P, Russell D, Osborne P, Bromley A, Rowland M, Creigh-Tyte S, Brown C. Economic costs of the foot and mouth disease outbreak in the United Kingdom in 2001. *Rev. Sci. Tech.* 2002; 21:675–687. [PubMed: 12523706]
- Thunes C, Carpenter TE. Biosecurity practices and travel history of individuals exhibiting livestock at the 2005 California State fair. *J. Am. Vet. Med. Assoc.* 2007; 231:581–585. [PubMed: 17696860]
- Tikofsky LL, Zadoks RN. Cross-infection between cats and cows: origin and control of *Streptococcus canis* mastitis in a dairy herd. *J. Dairy Sci.* 2005; 88:2707–2713. [PubMed: 16027183]
- Tiwari A, VanLeeuwen JA, Dohoo IR, Stryhn H, Keefe GP, Haddad JP. Effects of seropositivity for bovine leukemia virus, bovine viral diarrhoea virus, *Mycobacterium avium* subspecies *paratuberculosis*, and *Neospora caninum* on culling in dairy cattle in four Canadian provinces. *Vet. Microbiol.* 2005; 109:147–158. [PubMed: 15970402]
- Tyshenko MG. Bovine spongiform encephalopathy and the safety of milk from Canadian dairy cattle. *Vet. Rec.* 2007; 160:215–218. [PubMed: 17308017]
- USDA; APHIS; VS. Accessed April 30, 2009 Info sheet: Johne's disease on U.S. dairies 1991-2007. 2007 [http://nahms.aphis.usda.gov/dairy/dairy07/Dairy2007\\_Johnes.pdf](http://nahms.aphis.usda.gov/dairy/dairy07/Dairy2007_Johnes.pdf)
- Van Reijen MM, van Keulen PH, Kluytmans JA. Increase in a Dutch hospital of methicillin-resistant *Staphylococcus aureus* related to animal farming. *Clin. Infect. Dis.* 2008; 46:261–263. [PubMed: 18171259]
- Van Schaik G, Berends IM, van Langen H, Elbers AR, Vellema P. Seroprevalence of bluetongue serotype 8 in cattle in the Netherlands in spring 2007, and its consequences. *Vet. Rec.* 2008; 163:441–444. [PubMed: 18849575]
- Van Schaik G, Schukken YH, Nielen M, Dijkhuizen AA, Barkema HW, Benedictus G. Probability of and risk factors for introduction of infectious diseases into Dutch SPF dairy farms: A cohort study. *Prev. Vet. Med.* 2002; 54:279–289. [PubMed: 12114014]
- Van Weering H, van Schaik G, van der Meulen A, Waal M, Franken P, van Maanen K. Diagnostic performance of the Pourquier ELISA for detection of antibodies against *Mycobacterium avium* subspecies *paratuberculosis* in individual milk and bulk milk samples of dairy herds. *Vet. Microbiol.* 2007; 125:49–58. [PubMed: 17601689]
- Vandenbroucke-Grauls CM, Beaujean DJ. Methicillin-resistant *Staphylococcus aureus* in pig breeders and cattle breeders. *Ned. Tijdschr. Geneesk.* 2006; 150:1710–1712. [PubMed: 16924940]
- Veling J, Wilpshaar H, Frankena K, Bartels C, Barkema HW. Risk factors for clinical *Salmonella enterica* subsp *enterica* serovar Typhimurium infection on Dutch dairy farms. *Prev. Vet. Med.* 2002; 54:157–168. [PubMed: 12069778]

- Villarroel A, Dargatz DA, Lane VM, McCluskey BJ, Salman MD. Suggested outline of potential critical control points for biosecurity and biocontainment on large dairy farms. *J. Am. Vet. Med. Assoc.* 2007; 230:808–819. [PubMed: 17362152]
- Waage S. Influence of new infection with bovine virus diarrhoea virus on udder health in Norwegian dairy cows. *Prev. Vet. Med.* 2000; 43:123–135. [PubMed: 10673059]
- Wapenaar W, Barkema HW, O'Handley RM, Bartels CJ. Use of an enzyme-linked immunosorbent assay in bulk milk to estimate the prevalence of *Neospora caninum* on dairy farms in Prince Edward Island, Canada. *Can. Vet. J.* 2007; 48:493–499. [PubMed: 17542367]
- Wapenaar W, Jenkins MC, O'Handley RM, Barkema HW. *Neospora caninum*-like oocysts observed in feces of free-ranging red foxes (*Vulpes vulpes*) and coyotes (*Canis latrans*). *J. Parasitol.* 2006; 92:1270–1274. [PubMed: 17304805]
- Warnick LD, Nielsen LR, Nielsen J, Greiner M. Simulation model estimates of test accuracy and predictive values for the Danish *Salmonella* surveillance program in dairy herds. *Prev. Vet. Med.* 2006; 77:284–303. [PubMed: 16979767]
- Wellenberg GJ, van der Poel WH, van Oirschot JT. Viral infections and bovine mastitis: A review. *Vet. Microbiol.* 2002; 88:27–45. [PubMed: 12119136]
- Wells SJ. Biosecurity on dairy operations: Hazards and risks. *J. Dairy Sci.* 2000; 83:2380–2386. [PubMed: 11049083]
- Wilson DJ, González RN, Sears PM. Segregation or use of separate milking units for cows infected with *Staphylococcus aureus*: Effects on prevalence of infection and bulk tank somatic cell count. *J. Dairy Sci.* 1995; 78:2083–2085. [PubMed: 8550917]
- Windsor RS. Relating national veterinary services to the country's livestock industry: Case studies from four countries—Great Britain, Botswana, Perú, and Vietnam. *Ann. N. Y. Acad. Sci.* 2002; 969:39–47. [PubMed: 12381561]
- Wulf M, Voss A. MRSA in livestock animals—An epidemic waiting to happen? *Clin. Microbiol. Infect.* 2008; 14:519–521. [PubMed: 18325034]
- Yildirim AO, Lämmle C, Weiss R, Kopp P. Pheno- and genotypic properties of streptococci of serological group B of canine and feline origin. *FEMS Microbiol. Lett.* 2002; 212:187–192. [PubMed: 12113933]
- Zadoks RN. Sources and epidemiology of *Streptococcus uberis*, with special emphasis on mastitis in dairy cattle. CABI Publishing; Wallingford, UK: 2007. CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources 2
- Zadoks RN, Allore HG, Hagenaars TJ, Barkema HW, Schukken YH. A mathematical model of *Staphylococcus aureus* control in dairy herds. *Epidemiol. Infect.* 2002; 129:397–416. [PubMed: 12403116]
- Zadoks RN, Fitzpatrick JL. Changing trends in mastitis. *Ir. Vet. J.* 2009; 62(Suppl.):59–70.
- Zadoks RN, Gillespie BE, Barkema HW, Sampimon OC, Oliver SP, Schukken YH. Clinical, epidemiological and molecular characteristics of *Streptococcus uberis* infections in dairy herds. *Epidemiol. Infect.* 2003; 130:335–349. [PubMed: 12729202]
- Zadoks RN, Schukken YH. Use molecular epidemiology in veterinary practice. *Vet. Clin. North Am. Food Anim. Pract.* 2006; 22:229–261. [PubMed: 16517304]



**Figure 1.** Plot of average bulk milk SCC (BMSCC) in the Netherlands from November 1996 to January 2008, showing an extended seasonal elevation after the foot and mouth disease (FMD) outbreak compared with other years.